Sand wave fields beneath the Loop Current, Gulf of Mexico: reworking of fan sands

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Abstract

Extensive fields of large barchan-like sand waves and longitudinal sand ribbons have been mapped by deep-towed SeaMARC IA sidescan sonar on part of the middle and lower Mississippi Fan that lies in about 3200 m of water. The area is beneath the strongly flowing Loop Current. The bedforms have not been adequately sampled but probably consist of winnowed siliciclastic-foraminiferal sands. The size (about 200 m from wingtip to wingtip) and shape of the large barchans is consistent with a previously observed peak current speed of 30 cm/s, measured 25 m above the seabed. The types of small-scale bedforms and the scoured surfaces of chemical crusts, seen on nearby bottom photographs, indicate that near-bed currents in excess of 30 cm/s may sometimes occur. At the time of the survey the sand transport direction was to the northwest, in the opposite direction to the Loop Current but consistent with there being a deep boundary current along the foot of the Florida Escarpment. Some reworking of the underlying sandy turbidites and debris flow deposits is apparent on the sidescan sonar records. Reworking by deep-sea currents, resulting in erosion and in deposits characterised by coarsening upwards structures and cross-bedding, is a process that has been proposed for sand found in cores in shallower parts of the Gulf of Mexico. This process is more widespread than hitherto supposed.

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1. Introduction

Currents of various types are known to transport and deposit sand size material on the upper continental slope, e.g. Viana and Fauge\textsuperscript{res} (1998) for the Campos margin of Brazil and Kenyon (1986) for the northeast Atlantic. There is also growing evidence for the presence of abyssal currents strong enough to transport a significant amount of sediment, including material of silt and sand size when it is available, e.g. Hollister and McCave (1984). Fields of sediment waves and mega-furrows have been reported from deep-water surveys on the continental rise south of the Sigsbee Escarpment (Damuth et al., 1991; Bryant et al., 2000), which is in the Gulf of Mexico to the west of the present study area, and their
presence suggests that bottom currents there can have speeds of the order of 100 cm/s.

This paper describes the evidence for strong deep-sea currents in the eastern Gulf of Mexico, including new evidence from a deep-towed sidescan sonar and profiler survey that was followed by coring of selected sites. The extent to which turbidite systems can be modified by bottom currents is little known. It is suggested that turbidity current plumes can be transported laterally by contour currents (Shanmugam et al., 1993) and the same authors suggest that turbidite deposits on the upper Texas-Louisiana slope have been reworked by contour currents (Mutti et al., 1980; Barros et al., 1982). The main aims of this paper are to (1) add to the understanding of such reworking processes, (2) reassess their significance for the interpretation of ancient sequences, and (3) describe the extent of the current-swept area as a potential hazard to engineering structures in the deep Gulf of Mexico.

2. Existing data

It has long been known that there are strong bottom currents affecting the floor of the deep eastern Gulf of Mexico. Bottom photographs show evidence for a wide range of current strengths (Huang and Goodell, 1970; Pequegnat, 1972; Pequegnat et al., 1972). The relative strength of the current is estimated from a table deduced from features seen on bottom photographs (Tucholke et al., 1985; McCave and Tucholke, 1986). At sites in and around the De Soto Canyon there are undisturbed animal tracks, flocs of organic/mineral debris and some examples of weak current lineation (Pequegnat et al., 1972). On the table of relative current strength such features have values of between 1 and 3, where 1 is believed to be a tranquil environment with current speeds of less than 5 cm/s. At the photographic station located within the study area (Fig. 1) there are well developed fields of small transverse ripples with sharp cornice-like crests. Winnowed, coarse-grained sediments partly fill the ripple troughs. The relative current strength at this station is rated at somewhere around 5 or 6, which is believed to be indicative of current speeds of about 50 cm/s. At a cluster of photographic stations in similar depths, but to the south of the present study area and occupied in each of the four successive years between 1967 and 1970 (Pequegnat et al., 1972), the estimated conditions range from 1 to 8, with 8 being in excess of 50 cm/s.

Further evidence for strong bottom currents comes from consideration of iron-rich crusts, which are usually buried by Holocene hemipelagic oozes, but adjacent to the study area they are shown by photographs to be exposed at the seabed (Fig. 1). These iron-rich crusts were dredged up from those sites where the stronger currents were measured (Pequegnat, 1972).

A high-resolution deep-towed sidescan sonar and high-resolution profiler survey from the vicinity of the main Mississippi Channel and its levee (Prior et al., 1983) showed that there were transverse sand wave-like bedforms on the surface of the channel. These are believed to be formed from sand derived from shallow water. The levees appeared to be deeply eroded, as relatively steeply dipping reflectors outcrop at the surface (Prior et al., 1983; Twichell et al., 1996). The currents that caused these features may have been associated with down-channel flows. However, there may be continuing erosion by the strong bottom current responsible for the bedforms on the outer part of the fan (see Section 5).

3. Data acquisition

Complete 6.5 kHz GLORIA sidescan sonar coverage of the deep Gulf of Mexico was obtained as part of the USGS/IOS project to map the deeper part of the Exclusive Economic Zone of the USA (EEZ-Scan 85 Scientific Staff, 1987). Distal lobes with overall strong acoustic backscatter and with a distributary pattern of channel-like features are distinguished outside of the area of the main channel from this reconnaissance survey with long-range sidescan sonar (Twichell et al.,
Fig. 1. Location map of the study area and of the SeaMARC IA digital sidescan sonar mosaic (dashed line). The outline of the youngest of the Mississippi Fan lobes and the main lobe channels are shown (solid lines). Some bedforms from the western part of the area of sidescan coverage, near the proximal part of the feeder channel, are mapped in Twichell et al. (1996) and not illustrated in this paper. The location of Figs. 2–5 is shown.
One of these lobes has been surveyed with a deep-towed SeaMARC IA system (Fig. 1) (Twichell et al., 1992, 1995). This system has a 30 kHz sidescan sonar and a 4.5 kHz profiler. The two-way looking sidescan sonar has a tow speed of about 2.5 knots and tracks were usually about 4 km apart to allow for some overlap. Some of the coverage is navigated from acoustic beacons moored near the seabed. Cores were taken from sites that were selected to investigate the distal lobes and are described in Nelson et al. (1992) and Twichell et al. (1995). They are poorly sited for the purposes of this study and hence are not described again in this paper. Digital copies of the imagery and core results were released by Paskevich et al. (2000).

4. New observations

The SeaMARC IA system surveyed a portion of the main sinuous Mississippi Fan Channel in the region where there is a subsidiary branching channel (Fig. 1) that feeds one of the youngest of the major fan lobes described by Twichell et al. (1991, 1995, 1996). The levees of the main channel have a relief of about 100 m. The levees of the lobe feeder channel have a relief of about 50 m at their proximal end and decrease in height gradually until there is no noticeable relief at their distal end. The other main area of survey was the distal end of this fan lobe. This area is shown by Twichell et al. (1992, 1995) to have a dendritic distributary pattern. The level of acoustic backscatter recorded on both the GLORIA and SeaMARC IA sidescan sonars, from the lobes of the Mississippi Fan, is generally high. The areas of high backscatter are shown from studies of cores to be related to the distribution of clastic sands and silts (Kenyon, 1992; Nelson et al., 1992). As well as the acoustic patterns associated with gravity-driven flows there is a superimposed pattern of isolated crescentic features (Fig. 2) on the distal lobe, all of which are concave to the northwest, and of straight ribbon-like features aligned northwest–southeast (Fig. 3). The crescents tend to be grouped together in two or three belts stretching across the outer lobe (Fig. 4). They have a width (distance between wing tips) of up to 200 m. The ribbon-like features are up to 6 km long and are typically about 150 m apart. Sometimes they are aligned either side of the wing tips of the crescents (Fig. 2, lower inset) and sometimes they are in fields on their own (Fig. 5). The crescents and ribbons are very weakly backscattering and often have the lowest pixel values in the region. However, those ribbons that fall outside of the high backscattering sand lobes appear to be more strongly backscattering than the fine-grained sediments underlying them (Fig. 5). There is no measurable relief over these bedforms on either the shipboard or deep-towed profilers. Nor is there any evidence of shadows or steep faces on the sonographs. Thus, they are probably no more than 1–2 m high, the limit of resolution of the profiles. However, it is possible that no sand waves were crossed as they are fairly well separated (Figs. 2, 3 and 5).

These characteristics resemble those of certain kinds of bedform of non-cohesive sediments, namely low barchanoid sand waves and longitudinal sand ribbons, that are found in regions of relatively low sand supply, both on the continental shelf (Kenyon and Belderson, 1969; Belderson et al., 1982) and in deep water (Lonsdale and Malfait, 1974; Cochonat et al., 1989). Sand wave is the preferred term, as discussed in Belderson et al. (1982). They are also called sand dunes (Ashley, 1990).

A number of long, near-parallel stripes, also weakly backscattering, are found about 50 km west of the area reported on here, in the area...
surveyed near the junction of the lobe feeder channel with the main Mississippi Fan Channel (Fig. 1). They are also oriented northwest–south-east and cross zones of features associated with gravity-driven flows including the levees of the feeder channel. They are shown in figures 5 and 6 of Twichell et al. (1996) and described as possible sediment waves, but by analogy with the
features described here they may be a further example of sand ribbons, formed by the reworking of levee deposits by a bottom current.

5. Discussion

There are no ground-truthing data that prove the composition of the mobile bedforms. The bedforms may be composed of foraminifera-rich sands, winnowed from the veneer of Holocene foraminiferal ooze that covers most of the deep seabed in the Gulf of Mexico (Bouma, 1972; Huang and Goodell, 1970) and which are present in the surface layers of most of the cores obtained in this area (Nelson et al., 1992). An admixture of siliciclastic material can also be expected due to winnowing of terrigenous turbidites and debrites that lie beneath the seabed in the area. Sand waves formed of foraminiferal ooze probably require a threshold current of $30 \pm 10$ cm/s, according to Lonsdale and Malfait (1974), which is in keeping with the observed peak current speed. The resultant sedimentary bodies are thin sandy contourites (probably less than 2 m thick, the maximum predicted height of the sand waves) with a patchy distribution. The sands are probably foraminifera-rich and cross-bedded. It has been noted that the sidescan signature from a body of clean sand at or close to the seabed is usually weak (e.g. Gardner et al., 1991; Masson, 2001). In fact it has long been observed that well sorted, clean sands appear as relatively weakly backscattering areas on sidescan sonar records (see many examples in Belderson et al., 1972).

The barchans are all found within the limits of depositional lobes developing at the terminations of distributary channels emanating from the main
Mississippi Fan Channel (Fig. 4). The silty–sandy clastic material in the deposits forming the lobes is believed to be a major supplier of sand for these bedforms. Several generations of lobes were identified on the sidescan sonar images (Twichell et al., 1995) and the majority of the barchans appear to be associated with the youngest of the surveyed lobes, where silt/sand-rich deposits are either exposed at the seafloor or lie close to it. The depth to these sands and silts varies according to the age of the lobes and sublobes. A core from one of the oldest lobes, lying to the south of the study area and identified from GLORIA sidescan sonar and from seismic profiles by Twichell et al. (1991), has the top of the sands at 4 m downcore (Kenyon, 1992). Sublobes in the study area have been distinguished and placed in order of their deposition based on cross-cutting relationships seen on the SeaMARC IA sidescan sonar (Twichell et al., 1995). Two cores from the oldest of these sublobes have the top of the sands at approximately 2.35 m downcore (Nelson et al., 1992). A reap-

Fig. 5. Portion of the SeaMARC IA digital mosaic showing an extensive field of ribbon-like bedforms beyond the youngest of the sand lobes. Note the evidence for apparent reworking of sediments of the highly backscattering lobe and transport to the northwest (upper left). Dark tones represent low backscatter.
praisal of the 15 cores that are taken from the young and intermediate sublobes of Nelson et al. (1992) shows that the first siliciclastic sands are found at 8–66 cm downcore. There are no sand waves on the oldest of the sublobes. The sand waves are concentrated on the least buried of the sublobes perhaps because they are the most readily winnowed (Fig. 4). Further support for reworking of the underlying fan sands comes from the observation of ribbons emanating from the northern edge of the youngest and shallowest buried of the lobes (Fig. 5).

The trends of the studied bedforms are remarkably constant over the area at the time of the observations and generally are in agreement with the current measurements of Hamilton (1990) (Fig. 6). This northwest trending bedload transport path may also be present further west, near the feeder channel to the lobe, as northwest–southeast trending bedforms have been mapped here by Twichell et al. (1996).

The deep currents vary in direction (Hamilton, 1990) and thus there may be some periodic modification to the bedforms. However, the size of the
barchanoid sand waves is substantial and it may take a considerable time to alter their shape. Therefore they are believed to indicate a relatively long-term trend of the peak current to the northwest. The origin of the deep currents is not completely understood, although an attempt to explain their existence was made by Hamilton (1990), who related the deep currents with propagation of topographic Rossby waves generated by fluctuations of the Loop Current. The waves are estimated to propagate at speeds of 10–20 km/day. The OCCAM model (Webb, 2000) was run for current velocity in this region of the deep Gulf of Mexico. It did not resolve a current in the area of observed sand transport but to the south of the area there was an indication of a possible deep boundary current, running northwards, counter to the Loop Current, along the base of the Florida Escarpment.

6. Summary

The observations of fields of barchan-like sand waves and longitudinal sand ribbons indicate the presence of strong bottom currents in this part of the Gulf of Mexico. This is in keeping with nearby current measurements and bottom photographs. The lack of cores through these fairly isolated bedforms means that the geometry of the sandy contours is not known. The currents are believed to have reworked the youngest of the previously deposited turbidite and debris flow deposits, together with the hemipelagic foraminifera-rich drape, and are transporting sands to the northwest. Further investigations may show that this current is reworking sediments further west including the proximal part of the lobe and the levees of the main Mississippi Fan channel.

Shanmugam et al. (1993), on the basis of integration of well and 3-D seismic data, proposed a model in which some of the hydrocarbon-bearing sand bodies found in the Pliocene–Pleistocene sequence in the Ewing Bank area, upper slope, Gulf of Mexico, were formed as a result of bottom current reworking. By analogy with the present day situation (Pequegnat, 1972; Haustein and Feeney, 1985; Hamilton, 1990) the ancestral Loop Current was suggested to be a major bottom-current reworking agent. The data presented in this study can be considered as a recent example of the above model, extending the range of water depths where redeposition of clastic material by bottom currents can occur to over 3000 m.

In areas of weaker current, outside of the area where sand is being winnowed, one would expect silty and muddy contourite drifts. These should be sought within the Gulf of Mexico.

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